Extended abstract for paper selection at the 26th U.S. Symposium on Rock Mechanics, June 1985, Rapid City, SD.

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SAND84-2137A

# Physical and Numerical Simulations of Fluid Filled Cavities in a Creeping Material •

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## Introduction

The finite element method has been used for several years to calculate the creep closure of Strategic Petroleum Reserve storage cavities in rock salt. The two-dimensional axisymmetric finite element calculations performed thus far have required many simplifying assumptions to reduce the three-dimensional cavern geometries down to two dimensions. To gain an understanding of three-dimensional effects such as cavern spacing, scale model centrifuge testing has been employed. The first three centrifuge experiments were single cavity tests which employed the creeping material plasticine and were performed at three different accelerations. These were preliminary experiments to explore the feasibility of creep testing on the centrifuge. These experiments and the attending two dimensional finite element analysis are presented in this abstract. A set of multi-cavity centrifuge models is currently being assembled where the cavity spacing will be varied to gain an understanding of its influence. This set of experiments will also be simulated with a three-dimensional finite element program capable of creep calculations. The single and multiple cavity physical and numerical simulations will be included in the final paper.

## Single Cavity Centrifuge Experiments

Three identical centrifuge models were made with a cylindrical alcohol filled cavity in the center of a cylindrical block of green plasticine. The cavity was two inches in diameter and four inches high and the block was eleven inches in diameter and ten inches high. The models were loaded with a 1/4 inch sheet of annealed lead on top and at accelerations of 100, 125 and 150 G's on a six-foot centrifuge. Each model was held at its designated acceleration level for two hours experiencing creep closure due to the acceleration induced geostatic stress field. At the end of each test the models were frozen, cut in half and photographed. The boundaries of the cavities in the photographs were digitized and are shown in Figures 1, 2 and 3. The deformations are similar to those seen in fluid storage cavities in rock salt where there is some roof movement, floor heave, and increasing inward displacement from top to bottom along the side. The digitized boundaries were processed numerically to give the final cavity volumes that are presented later.

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• This work was performed at Sandia National Laboratories supported by the U.S. Department of Energy under Contract Number DE-AC04-76-DP00789 in support of the Strategic Petroleum Reserves Project.

## Material Properties

The material properties for the plasticine were determined from unconfined compression tests on cylindrical samples. The tests were performed at four different axial strain rates with each resulting in a different value of steady state stress. The strain rate and effective stress were fit to the well-known secondary creep equation

$$\dot{\bar{e}} = A\bar{\sigma}^n \qquad (1)$$

where

$\dot{\bar{e}}$ = secondary creep strain rate

$\bar{\sigma}$ = effective stress

A = laboratory determined constant

n = laboratory determined stress exponent

Youngs modulus was determined from the slope of the elastic portion of the stress-strain curve. The material properties are given in Table I.

Table I

Material Properties for Plasticine

Youngs Modulus = 800 psi

Poissons Ratio = 0.48

$A = 1.19 \times 10^{-17}$ $1/(\text{sec psi}^n)$

n = 10.1

## Finite Element Simulations

The finite element program employed in this study has been used to predict creep closure of underground nuclear waste storage drifts [1] [2] and petroleum storage caverns in rock salt [3] [4] [5]. The finite element model of the fluid-filled cavity in plasticine is shown in Figure 4. The model loading consists of body forces, a surcharge on top of the model and fluid pressure inside the cavity. All of these are scaled with acceleration. The predicted closure after the test has been completed and the acceleration loads have been removed is shown in Figure 5 for the 125 G test. A comparison between the finite element predictions and the centrifuge experiments is shown in Figure 6 where percent volume closure is plotted against acceleration. This figure shows a relatively good comparison at 100 and 125 G's but a large error at 150 G's. The discrepancy in this test is not fully understood at this time but could have resulted from a reduction of fluid head in the cavity during the test or the triggering of another creep mechanism in the plasticine at the higher stress level.

These three experiments were preliminary tests to demonstrate the feasibility creep testing on the centrifuge. The results were encouraging and more experiments will be performed. Future work will include a suite of multi-cavity experiments with a central cavity and three surrounding cavities at equal distance. The spacing between the central and surrounding cavities will be varied in an attempt to understand the influence of spacing on cavity performance. These experiments will be performed at 125 G's to avoid the problems previously encountered at 150 G's.

## References


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[2] "Reference Calculations For Underground Rooms of the WIPP," Miller, J. D., Stone, C. M., and Branstetter, L. J., Sandia National Laboratories, SAND82-1176.

[3] "Verification of Finite Element Methods Used to Predict Creep Closure of Leached Salt Caverns," Preece. D. S. and Stone, C. M. Proceedings of 23rd Symposium on Rock Mechanics, Berkeley, Calif.

[4] "Finite Element Analysis of Salt Caverns Employed in the Strategic Petroleum Reserve With Comparison to Field Data," Preece, D. S. and Foley, J. T.. In Situ, Volume 8, Number 3. 1984.

[5] "Leached Salt Cavern Design Using a Fracture Criterion for Rock Salt ," Preece, D. S., and Wawersik, W. R., Proceedings of 25th Symposium on Rock Mechanics, Northwestern University, June, 1984.

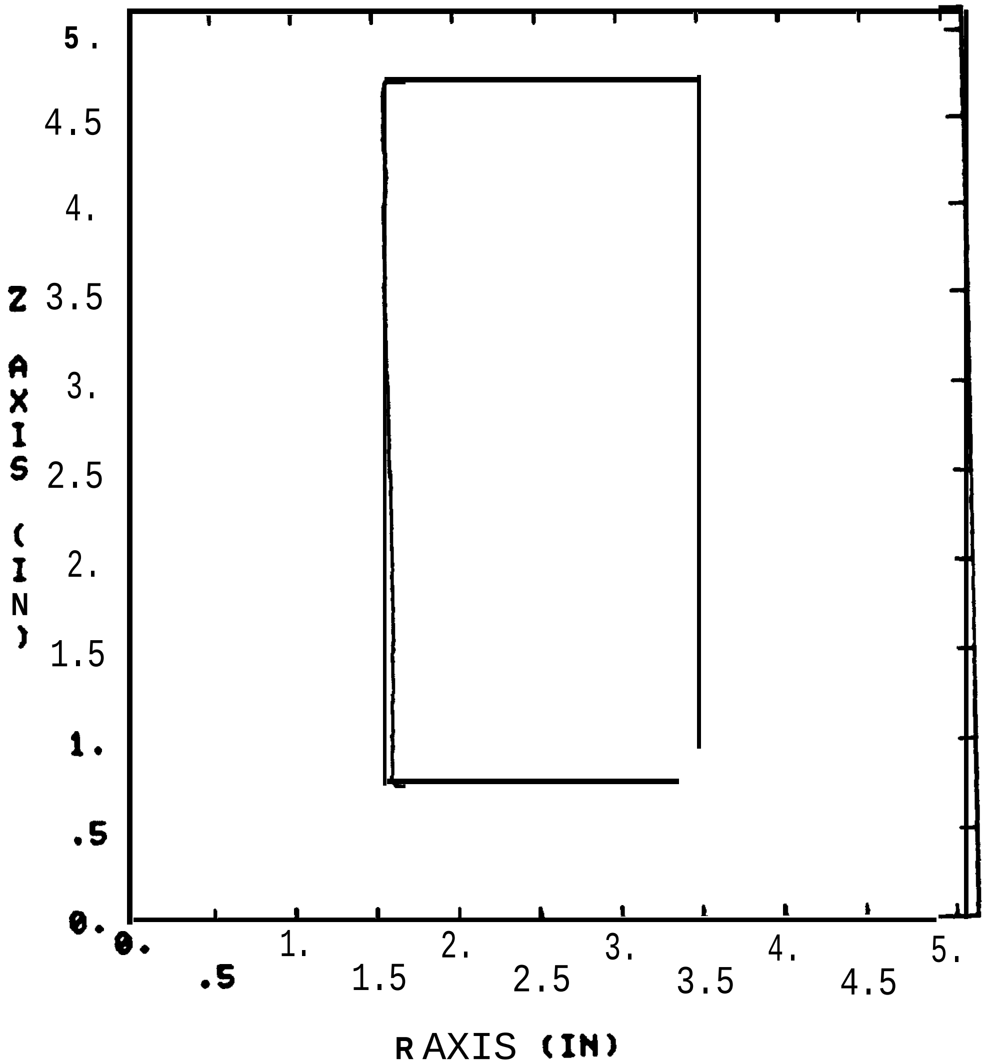


FIGURE 1

CAVITY SHAPE AFTER TWO HOURS OF CENTRIFUGE TESTING AT 100 G's

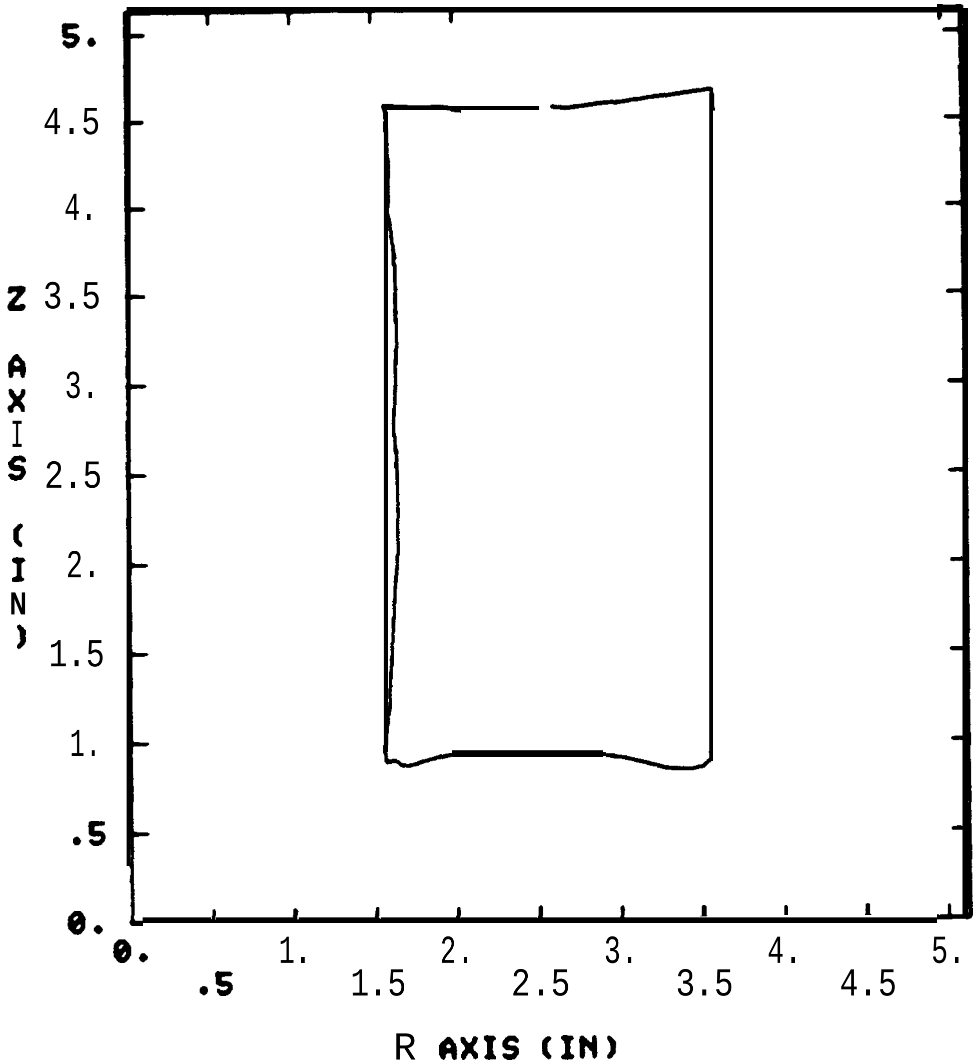


FIGURE 2

CAVITY SHAPE AFTER TWO HOURS OF
CENTRIFUGE TESTING AT 125 G's

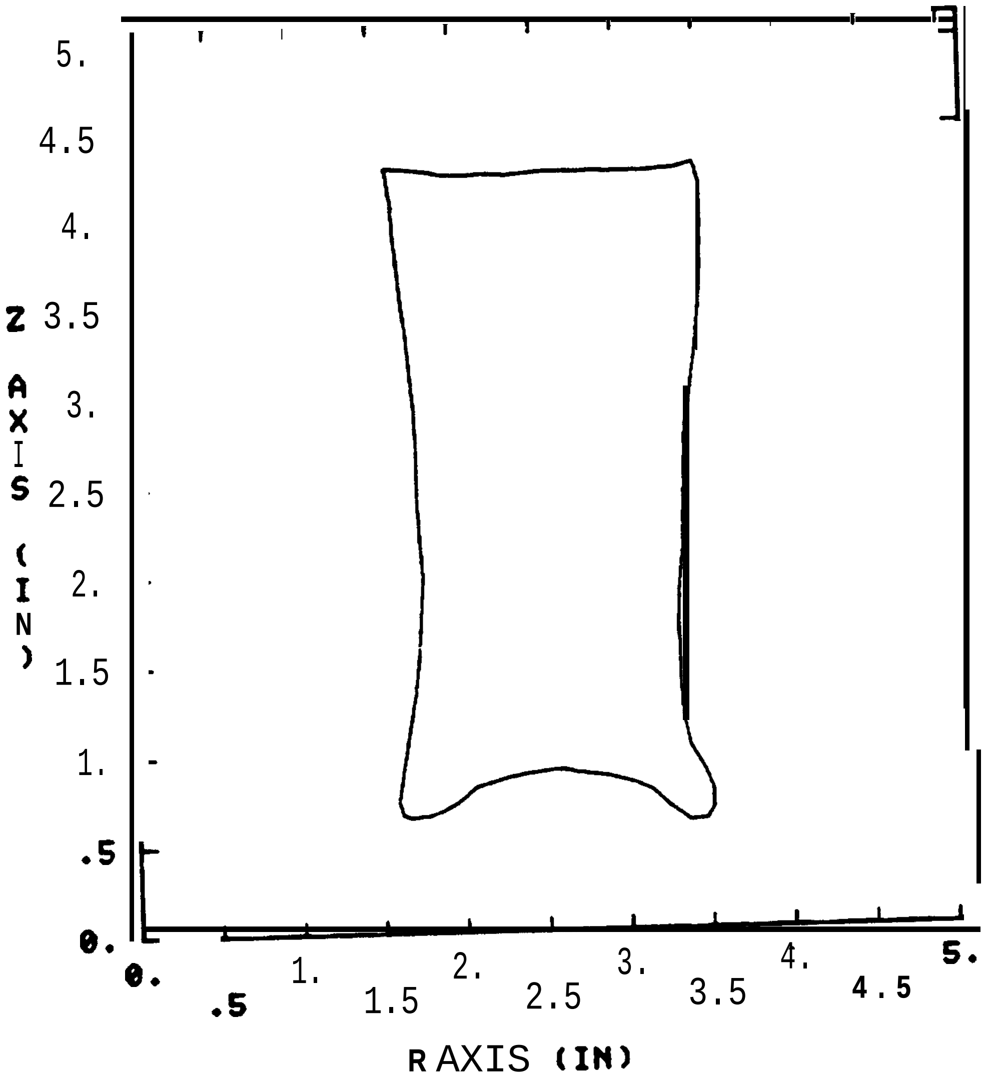


FIGURE 3

CAVITY SHAPE AFTER TWO HOURS OF
CENTRIFUGE TESTING AT 150 G's

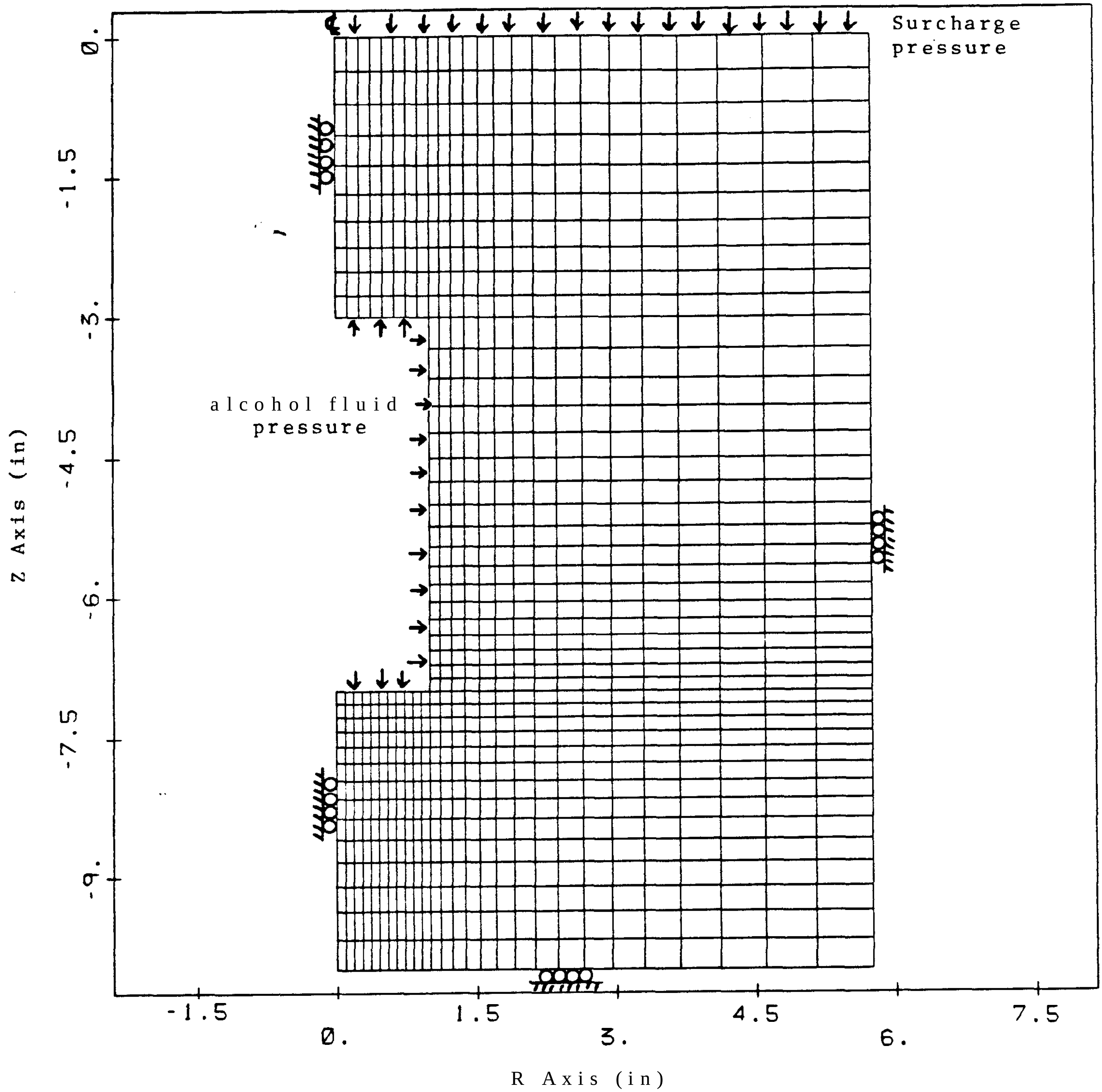


FIGURE 4

AXISYMMETRIC FINITE ELEMENT MODEL

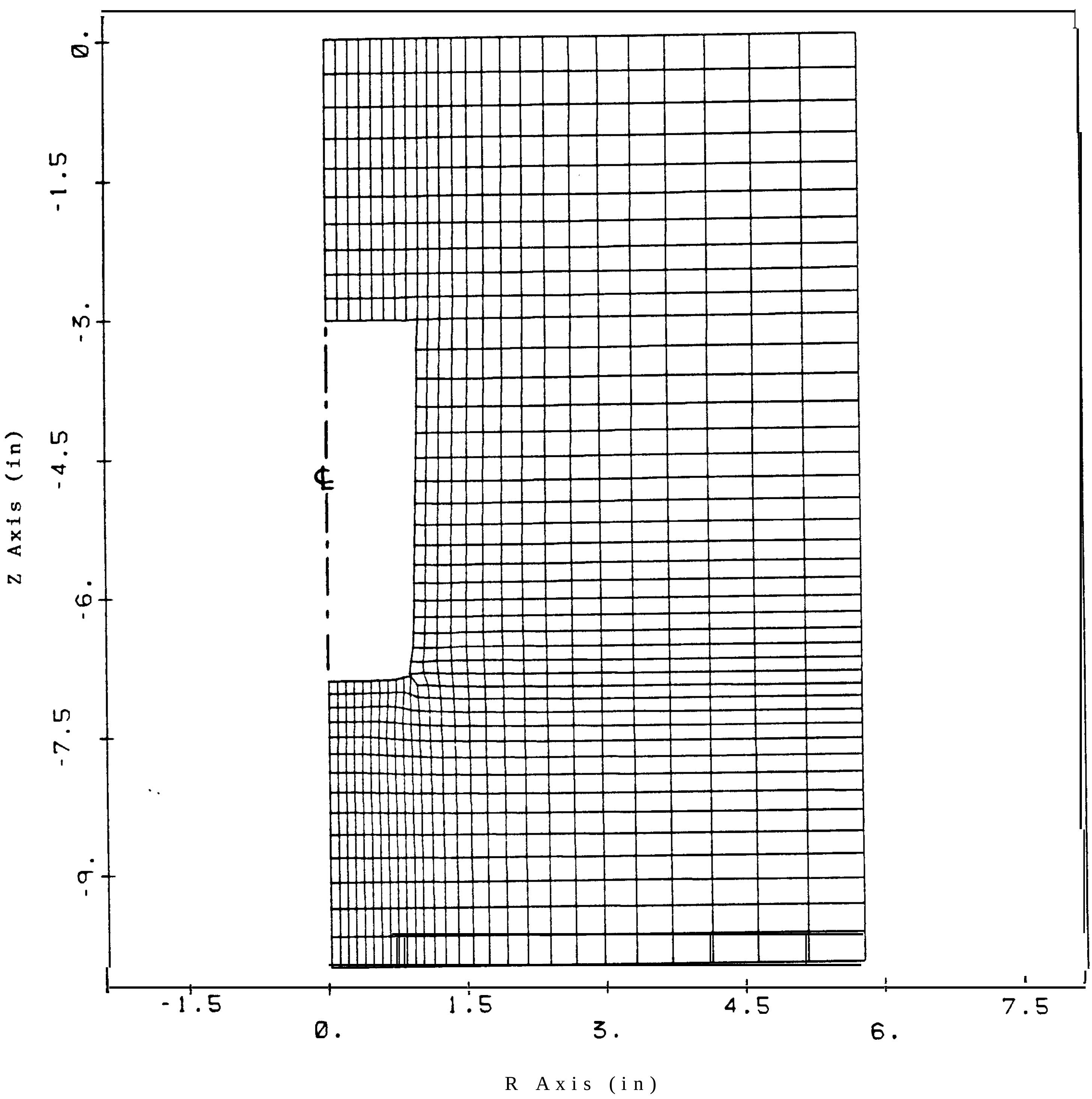


FIGURE 5

DEFORMED FINITE ELEMENT MESH SIMULATING
TWO HOURS OF CENTRIFUGE TESTING AT 125 G's

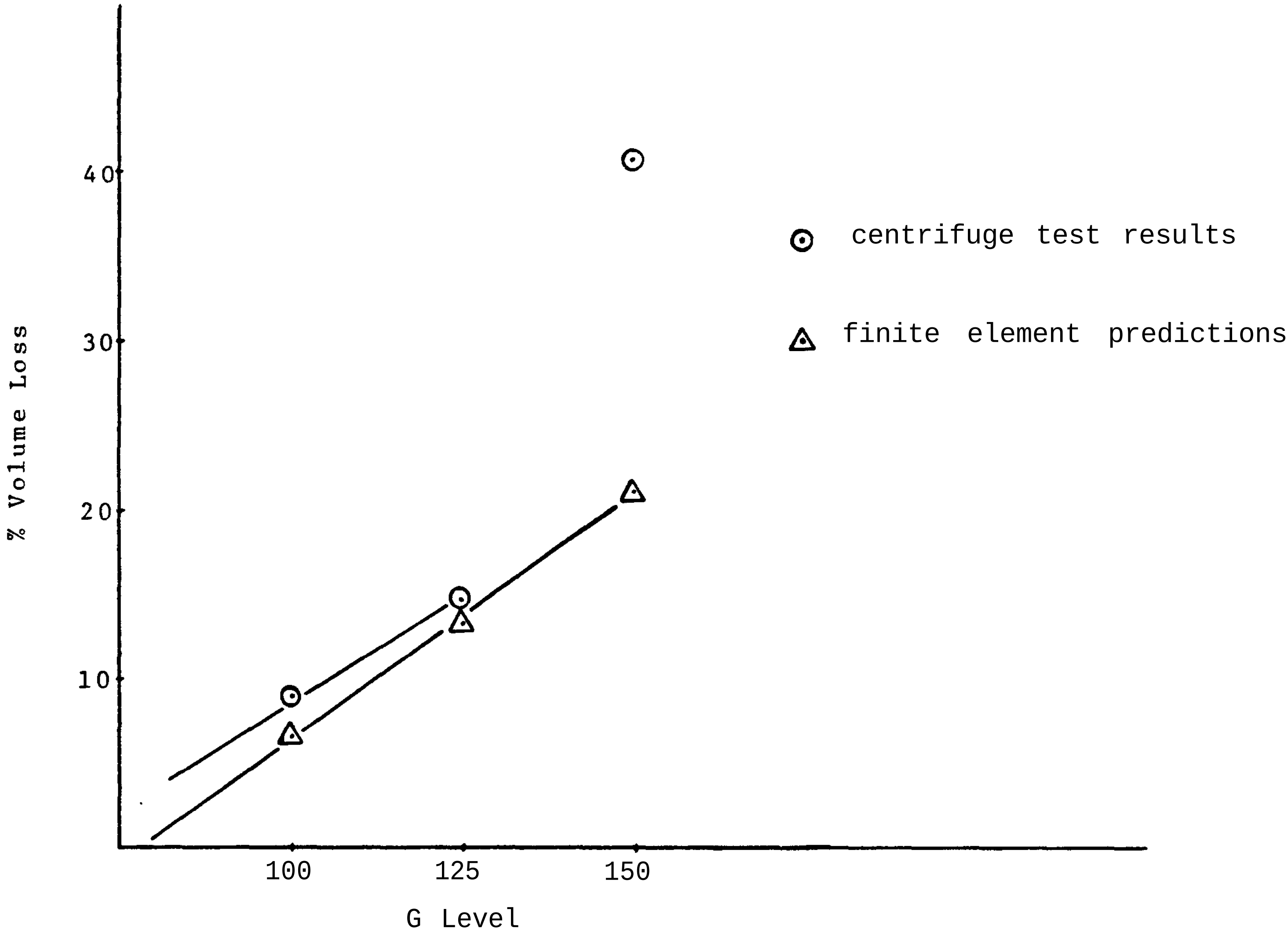


FIGURE 6

PERCENT VOLUME LOSS IN THE CAVITY VERSUS
G LEVEL FOR TWO HOURS OF CENTRIFUGE TESTING